IS 7396-2 (1985): Criteria for hydraulic design of surge tanks, Part 2: Tail race surge tanks [WRD 14: Water Conductor Systems]

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CRITERIA FOR HYDRAULIC DESIGN OF SURGE TANKS

PART 2 TAIL RACE SURGE TANKS

(First Revision)

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PART 2 TAIL RACE SURGE TANKS

(First Revision)

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Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF SURGE TANKS

PART 2 TAIL RACE SURGE TANKS

(First Revision)

0. FOREWORD

0.1 This Indian Standard (First Revision) was adopted by the Indian Standards Institution on 31 January 1985, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 In an underground development, tail race surge tanks are usually provided to protect tail race tunnel from water hammer effect due to fluctuation in load. These are located downstream of turbines which discharge into long tail race tunnels under pressure. The necessity of tail race surge tank may be eliminated by ensuring free-flow conditions in the tunnel but in case of long tunnels this may become uneconomical than a surge tank.

0.3 This standard was first published in 1975. This revision has been made in view of the experience gained during the use of this standard. The following additions have been made in this revision:

a) Worst conditions for the design of tail race surge tanks,

b) Manning's formula for calculating the friction losses, and

c) Requirements for providing system of drifts and galleries with drainage.

0.4 Depending upon the type of development, tail race surge tank may be a single surge tank downstream of turbine or may form a multiple surge tank system with head race surge tank.

0.5 Various types of development with tail race tunnel are classified into the following from the point of view of hydrodynamics of tail race surge tank (*see* Fig. 1):

Type A — Free-flow tail race tunnel without tail race surge tank,

Type B — Tail race pressure tunnel with tail race surge tank,

Type C — Tail race tunnel flowing either free or under pressure depending on tail water level condition, and

Type D — Systems of head race and tail race surge tanks hydraulically connected.

0.5.1 Arrangement of Type A is usual with development with almost constant tailwater level. The tunnel is designed to accommodate surges, if any, which are covered in IS : 7916-1975*. In case of long tunnels this may be uneconomical.

0.5.2 Arrangement of Types B and C have only a single tail race surge tank.

0.5.3 Details of Type D of surge tank system are shown in Fig. 2.

0.6 This standard is being prepared in parts. Other parts of this standard are as follows:

Part 1 Simple, restricted orifice and differential surge tanks,

Part 3 Special surge tanks (under preparation), and

Part 4 Multiple surge tank systems.

0.6.1 Surges in open channels are covered in IS : 7916-1975*.

1. SCOPE

1.1 This standard (Part 2) lays down the criteria for hydraulic design of tail race surge tank, hydraulically connected with a head race surge tank or without it (that is, Types B, C and D). However this does not cover tail race surge tanks for pumped storage power houses.

2. NOTATIONS

2.1 For the purpose of this standard, the following notations shall have the meaning indicated against each:

A_{s_1} = Cross-sectional area of head race surge tanks;

$A_{s_1}\ min$ = minimum As_1;

A_{s_2} = cross-sectional area of tail race surge tank;

$A_{s_2}\ min$ = minimum A_{s2};

A_{t_1} = equivalent areas of head race tunnel;

*Code of practice for open channels.

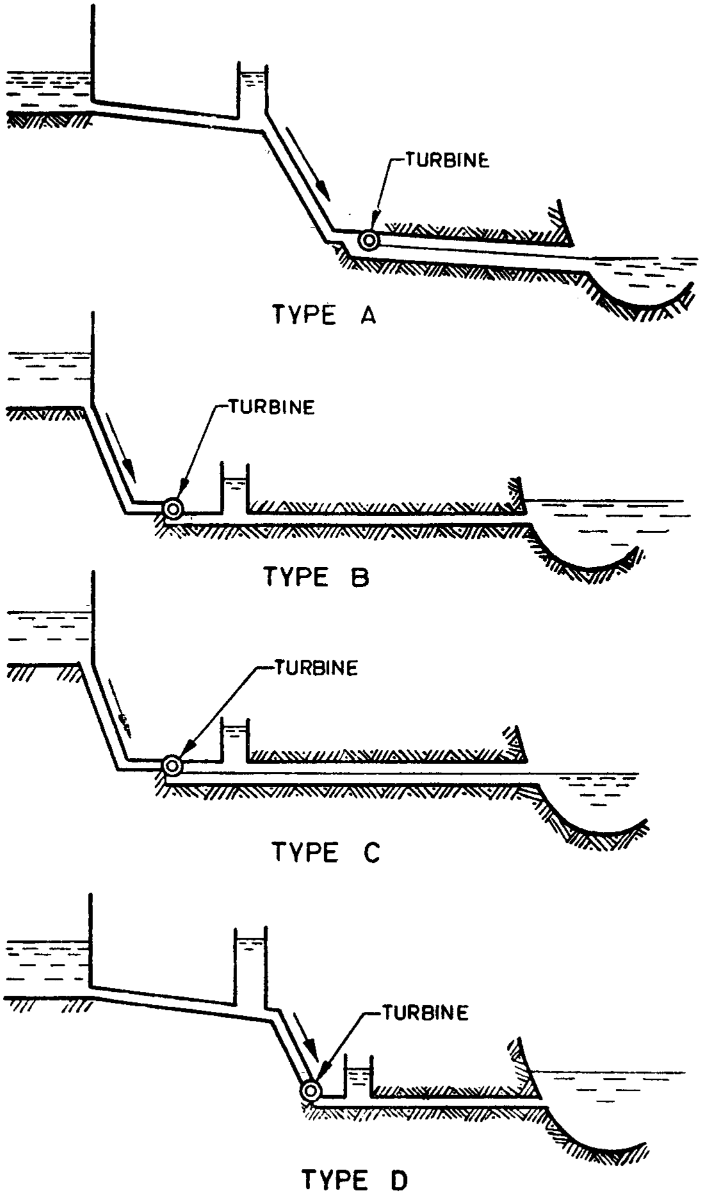

Fig. 1 Different Types of Tail Race Development

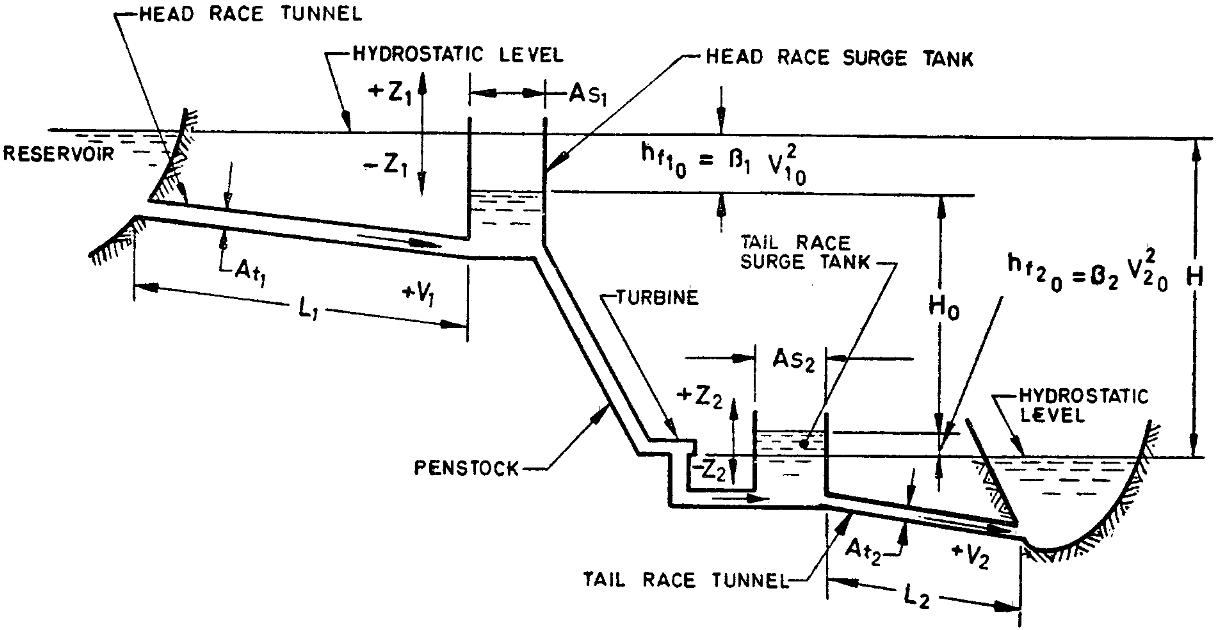

Fig. 2 System of Head Race and Tail Race Surge Tanks Hydraulically Connected

NOTE — When the tunnel cross-section comprises various lengths L_i of area At_i, At_1 may be taken as equivalent area of head race tunnel

$$= \frac{\Sigma L_i}{\sum \left(\frac{L_i}{At_i} \right)}$$

At_2 = equivalent area of tail race tunnel;

NOTE — When the tunnel cross-section comprises various lengths L_i of area At_i, At_2 may be taken as equivalent area of tail race tunnel

$$= \frac{\Sigma L_i}{\sum \left(\frac{L_i}{At_i} \right)}$$

Ath_1 = thoma area of head race surge tank;

Ath_2 = thoma area of tail race surge tank;

g = acceleration due to gravity;

H = gross head on turbine, that is (reservoir water level—turbines nozzle level), in the case of pelton wheel turbines and (reservoir water level — downstream tailwater level) in the case of reaction turbines;

H_0 = net head on turbine;

hf_p = head loss in penstock;

L_1 = length of head race tunnel;

L_2 = length of tail race tunnel;

P = power generated;

Q = discharge through turbine at any instant;

Q_0 = discharge through turbine under steady state condition;

t = time reckoned from start of transient;

T_1 = period of oscillation for head race surge tank;

T_2 = period of oscillation for tail race surge tank;

V_1 = velocity of flow in head race tunnel at any instant;

V_2 = velocity of flow in tail race tunnel at any instant;

V_{10} = velocity of flow in head race tunnel corresponding to steady state flow;

V_{20} = velocity of flow in tail race tunnel corresponding to steady state flow;

hf_{10} = total head loss in the head race tunnel up to surge tank in steady state condition;

hf_{20} = total head loss in the tail race tunnel beyond surge tank in steady state condition;

Hf_1 = friction loss in head race surge tank in steady state condition;

Hf_2 = friction loss in tail race surge tank in steady state condition;

Z_1 = surge height in head race surge tank from reservoir level measured positive upwards;

Z_2 = surge height in tail race surge tank from tail water level measured positive upwards;

β_1 = coefficient of hydraulic losses for head race tunnel up to surge tank; and

β_2 = coefficient of hydraulic losses for tail race beyond tail race surge tank.

3. TERMINOLOGY

3.1 For the purpose of this standard, the definitions given in IS : 7396 (Part 1)-1974* shall apply.

4. DATA REQUIRED

4.1 In addition to the data enumerated in IS : 7396 (Part 1)-1974*, the following data are required for the design:

a) Length, cross-section and maximum discharge through tail race tunnel; and

b) Maximum and minimum tail water levels at the exit of tail race tunnel.

5. DESIGN

5.1 Design Conditions — The tail race surge tank shall be designed to accommodate the maximum and minimum water level anticipated under worst condition as enumerated under **5.1.1** and **5.1.2**.

5.1.1 The maximum upsurge level in the surge tank shall be worked out corresponding to:

a) the full load acceptance at the highest downstream tail water level; and

b) where considered necessary, load rejection followed by specified load acceptance at the instant of maximum negative velocity in the tail race tunnel, the downstream tail water level being at its highest and higher of the two shall be adopted.

*Criteria for hydraulic design of surge tanks : Part 1 Simple, restricted orifice and differential surge tanks.

5.1.2 The minimum down surge level in the surge tank shall be worked out corresponding to:

a) the full load rejection at the lowest downstream tail water level; and

b) where considered necessary specified load acceptance followed by full load rejection at the instant or maximum positive velocity in the tail race tunnel the downstream tail water level being at its lowest and the lower of the two shall be adopted.

NOTE — This presumes that the load acceptance or rejection by different turbines in the stations shall be such as not to create super position of surge.

5.1.3 For tunnels flowing full, friction loss may be calculated either by using Manning's formula or Darcy-Weisbach formula:

5.1.3.1 *Manning's formula*:

The formula is given below:

$$h_f = \frac{V^2 N^2 L}{R^{4/3}}$$

where

h_f = head loss due to friction in metres;

V = velocity of water in the tunnel, in m/s;

N = rugosity co-efficient;

L = length of the tunnel, in metres; and

R = hydraulic radius

$$\left(\frac{\text{Area}}{\text{Wetted Perimeter}}\right)\text{, in metres.}$$

5.1.3.2 For concrete lined tunnels, the value of N varies from 0·012 to 0·014.

5.1.3.3 For unlined tunnels, the value of N depends upon the nature of rock and the quality of trimming. Recommended values of N for various rock surface conditions are given below:

Surface characteristics	*Value of N*	
	Minimum	*Maximum*
Very rough	0·04	0·06
Surface trimmed	0·025	0·035
Surface trimmed and invert concreted	0·02	0·03

5.1.3.4 The values of β shall then be determined from the following formula:

$$\beta V^2 = \frac{V^2 N^2 L}{R^{4/3}} + \text{Other losses in tunnel system.}$$

5.1.3.5 *Darcy-Weisbach formula*

The formula is given below:

$$hf = \frac{fL}{D} \times \frac{V^2}{2g}$$

5.1.3.6 The value of β shall then be calculated from the following formula:

$$\beta V^2 = \frac{f L V^2}{2 g D} + \text{Other losses in tunnel system.}$$

5.2 Criteria for stability shall be ensured for the tail race surge tank functioning as single surge tank or functioning in unison with head race surge tank.

5.2.1 Tail surge tank functioning as single surge tank for the arrangement in Types B and C shall satisfy the Thoma criteria for stability and the dimension of the surge tank shall be fixed as for a simple surge tank given in IS : 7396 (Part 1)-1974*.

5.2.2 Where the tail race surge tank is functioning in unison with head race surge tank (Type D) the minimum cross-section of head race and tail race surge tanks shall satisfy the criteria given below to ensure stability:

$$Ath_1 = \frac{At_1 \cdot L_1}{2 g \beta_1 H_0} \quad \ldots(1)$$

$$Ath_2 = \frac{At_2 \cdot L_2}{2 g \beta_2 H_0} \quad \ldots(2)$$

$$As_1\, min = (1 + C_t r)\ Ath_1 \quad \ldots(3)$$

$$As_2\, min = \left(1 + \frac{C_t}{r} \right) Ath_2 \quad \ldots(4)$$

where r is given by equation (5), and C_t is a constant and function of oscillation periods of two tanks. Value varies over a very wide limit (from 0·2 to 1·0).

For preliminary design a value of $C_t = 0·7$ may be assumed

$$r = \frac{As_1\ min}{As_2\ min} \quad \ldots(5)$$

Also, $As_1\, min = (r + C_t)\ Ath_2 \quad \ldots(6)$

*Criteria for hydraulic design of surge tanks: Part 1 Simple, restricted orifice and differential surge tanks.

5.2.3 From equations given in **5.2.2** stability curve shown in Fig. 3 is obtained to separate the stable and unstable regions. The greater of the values of As_1 *min* obtained from equation (1) and (6) shall be taken to obtain stability curve. The values of As_1 and As_2 adopted shall fall within stable zone.

5.2.4 The cross-sectional area adopted shall be such as not to create resonance between the oscillation in two tanks, that is, the ratio of oscillation periods, T_1/T_2, shall be outside the range 0·8 to 1·2. The ratio of oscillation periods is expressed as:

$$\frac{T_1}{T_2} = \sqrt{\frac{L_1\,At_2}{L_2\,At_1} \times \frac{As_1}{As_2}} \qquad \ldots(7)$$

or

$$As_1 = \frac{L_2\,At_1}{L_1\,At_2}\left(\frac{T_1}{T_2}\right)^2 \times As_2 \qquad \ldots(8)$$

The straight lines plotted for $T_1/T_2 = 0{\cdot}8$ and $T_1/T_2 = 1{\cdot}2$ form the limit lines for range of possible resonance. The values of As_1 and As_2 shall not fall in this zone as shown in Fig. 3 to avoid resonance.

5.2.5 The size of surge tanks to be adopted finally is also governed by topographical and geological conditions at surge tank sites.

5.3 Factor of Safety — The minimum size (area) of surge tank obtained from **5.2** be increased to ensure proper functioning of the system [refer IS : 7396 (Part 1)-1974*].

5.4 Surge Analysis

5.4.1 The distance between the tail race surge tank and draft tube shall be as short as possible to reduce the negative water hammer waves developing in the draft tube.

5.4.2 The extreme water levels in the two surge tanks for the conditions enumerated in **5.1** are determined by integrating numerically the equations of mass oscillation for the two surge tanks along with governing equations. The dynamic and continuity equations shall be modified suitably for any particular type of surge tanks, that is, simple, differential or restricted orifice surge tanks.

5.4.3 The basic equations for double simple surge tank system are as follows (*see* Fig. 3):

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*Criteria for hydraulic design of surge tanks: Part 1 Simple, restricted orifice and differential surge tanks.

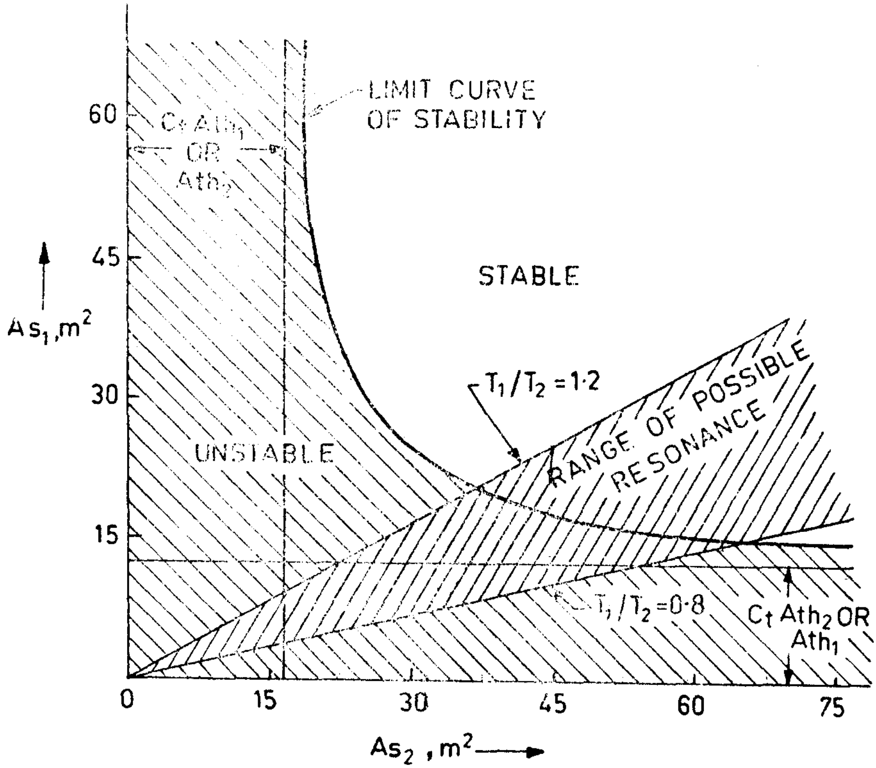

FIG. 3 CRITICAL STABILITY CURVE FOR A SURGE TANK SYSTEM

a) *Dynamic equation*

$$\frac{L_1}{g} \cdot \frac{dV_1}{dt} + Z_1 \pm \beta_1 V_1^2 \pm \frac{V_1^2}{2g} = 0 \qquad \text{...(9)}$$

$$\frac{L_2}{g} \cdot \frac{dV_2}{dt} - Z_2 \pm \beta_2 V_2^2 \pm \frac{V_2^2}{2g} = 0 \qquad \text{...(10)}$$

b) *Continuity equation*

$$At_1 . V_1 = As_1 . \frac{d Z_1}{d_t} + Q \qquad \text{...(11)}$$

$$Q = As_2 . \frac{d Z_2}{dt} + At_2 V_2 \qquad \text{...(12)}$$

c) *Governing equation at constant output*

$$P = K_m Q_0 \left(H \mp \beta_1 V_{10}^2 \mp \beta_2 V_{20}^2 - hf_p \pm \frac{V_{10}^2}{2g} \mp \frac{V_{20}^2}{2g} \right)$$

$$= K_m Q_0 \left(H \pm Z_1 \mp Z_2 \pm \frac{V_{10}^2}{2g} \mp \frac{V_{20}^2}{2g} \right)$$

NOTE — Positive value of $\beta_1.V_1^2$ or $\beta_2.V_2^2$ shall be used when the flow is downstream and negative when it is upstream.

6. HEIGHT OF SURGE TANK

6.1 Height of surge tank shall be fixed as specified in **6** of IS : 7396 (Part 1)-1974*.

7. GENERAL REQUIREMENTS

7.1 In order to obtain as much geological information as possible before hand and to suggest suitable design it is advised to provide an exploratory drift. The drift should be located as close to the proposed surge shaft as possible. In most of the cases, it would be ideal to locate the drift in such a manner that it could be later enlarged and used for ventilation and access cum expansion chamber. The size and shape of the expansion chamber could be designed suitably based upon the geological information obtained from the drift. The extent of seepage water likely to be met could also be gauged from the data obtained in exploratory drift and suitable drainage system could be suggested. Depending upon the quantity of seepage water met with, either a set of drainage holes or a system of collecting galleries located around the surge shaft may be provided to tap the water and prevent the build up of excessive water pressure behind the surge shaft lining.

7.2 For all important works the hydraulic aspects may be studied on hydraulic models.

7.3 Water level indicators and or recorders for both the surge tanks should be provided in control room for controlling the load acceptance.

*Criteria for hydraulic design of surge tanks : Part 1 Simple, restricted orifice and differential surge tanks.

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